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Test Plan for the Evaluation of the Initial Capability of the National Satellite Test Bed: Phase ID

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Final Report

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16. Abstract

This document contains a plan for testing Wide-area Differential GPS (WDGPS) and Wide-area Integrity Broadcast (WIB) concepts in the National Satellite Test Bed (NSTB). This report documents the test plan for the next test subphase (ID), and covers the flight test definition, data collection, reduction and analysis, organizational responsibilities, and schedule. The specific objectives of the testing during this subphase are to: (1) obtain data on the time to detect, transmit, process, and receive an integrity alarm using a satellite broadcast relay of the alarm from the ground to the test aircraft, (2) obtain preliminary data on the performance of WDGPS, and specifically of ionospheric corrections for WDGPS using a satellite broadcast of the differential corrections, and (3) compare the performance achieved with WDGPS with that of Local-area Differential GPS (LDGPS).

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ABSTRACT

This document contains a plan for testing Wide-area Differential GPS (WDGPS) and Wide-area Integrity Broadcast (WIB) concepts in the National Satellite Test Bed (NSTB). This report documents the test plan for the next test subphase (ID), and covers the flight test definition, data collection, reduction and analysis, organizational responsibilities, and schedule. The specific objectives of the testing during this subphase are to: (1) obtain data on the time to detect, transmit, process, and receive an integrity alarm using a satellite broadcast relay of the alarm from the ground to the test aircraft, (2) obtain preliminary data on the performance of WDGPS, and specifically of ionospheric corrections for WDGPS using a satellite broadcast of the differential corrections, and (3) compare the performance achieved with WDGPS with that of Local-area Differential GPS (LDGPS).

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SECTION 1

INTRODUCTION

This document contains a plan for testing Wide-area Differential GPS (WDGPS) and Wide-area Integrity Broadcast (WIB) concepts in the National Satellite Test Bed (NSTB). The FAA and STel are currently developing the NSTB at the FAA Technical Center (FAATC) in Atlantic City, NJ. The NSTB is being developed and tested in three phases. Phase I involves WIB and WDGPS testing using separate ionospheric corrections and lumped ephemeris and satellite clock corrections. Phase II will improve WDGPS and WIB performance by separating the ephemeris and satellite clock errors of each satellite. In phase III, the use of the WIB satellite as an additional ranging source will be investigated. The NSTB is currently in phase I of the development.

Phase I has been subdivided into four subphases. The first three subphases, IA, IB, and IC, have been completed. The purpose of subphase IA was to statically checkout the NSTB using equipment in the lab. The purpose of subphase IB was to determine the performance of WIB using a Very High Frequency (VHF) data link to the test aircraft. The purpose of subphase IC was to verify the WIB integrity algorithm using a GPS satellite simulator. The purpose of subphase ID, the subject of this test plan, is to measure the performance of the integrity time-to-alarm and the performance of WDGPS when using a geostationary satellite to broadcast the "don't use" message and the differential corrections.

The specific objectives of the testing during phase ID are to:

a. Obtain data on the time it takes the WIB to detect, transmit, process, and receive an integrity alarm using a geostationary satellite broadcast relay of the alarm to the test aircraft. (Test Objective 1).

b. Obtain preliminary data on the performance of WDGPS, and specifically of ionospheric corrections for WDGPS, using a geostationary satellite broadcast of the differential corrections. (Test Objective 2).

c. Compare the results using WDGPS with the results from using Local-area Differential GPS (LDGPS). (Test Objective 3).

The tests described in this plan are expected to be conducted during the month of August 1993.

SECTION 2

OVERALL GROUND RULES FOR INTERPRETING RESULTS OF THE TEST

The overall ground rules for interpreting the results of the test are provided below. Specific ground rules for conducting the test are provided in section 5.3.

a. The purpose of the test is to collect data to support the evaluation of WIB and WDGPS performance. The main data of interest are timeliness of integrity alarms and WDGPS performance in terms of sensor errors (SEs). The test will also collect data on flight technical errors (FTEs) and total system errors (TSEs).

b. As specified below, there will be an approval procedure for the release of any data or results of these tests.

c. The WIB and WDGPS systems that are being evaluated in this test are in the first of a three phase development effort and are not final systems. Specifically:

    i. lumped ephemeris and clock corrections are being used rather than separate corrections;

    ii. the message format being used in this test allows for the broadcast of corrections for only 24 satellites and 77 ionospheric grid points rather than 50 satellites and a variable number of ionospheric grid points as is being proposed by RTCA SC-159.

SECTION 3

SUCCESS CRITERIA

Since the system being evaluated in this test is not a final system, it is not necessary for specific accuracy or integrity requirements to be exactly achieved at this time. However, the results obtained during the test should be close to the requirements, and should permit the identification of specific improvements to enable the Phase II system to meet the requirements.

3.1 SUCCESS CRITERIA FOR TEST OBJECTIVE 1

For Test Objective 1 the goal is 6 seconds for the integrity time-to-alarm. This requirement is a more stringent one than what GPS integrity broadcast (GIB), the predecessor to WIB, was originally expected to achieve. GIB was originally expected to be used for all phases of flight from en-route through nonprecision approach where the time-to-alarm requirement is 10 seconds. The reason for the more stringent goal in this test is to determine if WIB can provide integrity for near CAT I precision approaches.

3.2 SUCCESS CRITERIA FOR TEST OBJECTIVE 2

For Test Objective 2 the goal of the WDGPS system is to achieve near Category I (CAT I) sensor performance as indicated in table 1, and CAT I operational performance based on the "tunnel" total system accuracy as indicated in table 2. The sensor accuracy requirements for near CAT I have not yet been firmly established but are based on the CAT I requirements in [1]. The total system accuracy requirements are defined in [2].

Table 1. Navigation Requirements for WDGPS – Sensor Accuracy

	Sensor Accuracy 2 sigma (meters)	
Sensor Category	Lateral	Vertical
Near CAT I	± 17.1	± 7

Table 2. Navigation Requirements for WDGPS – Total System Accuracy

Operational Category	Total System Accuracy 95 percent (meters) Lateral	Vertical	Decision Height
CAT I	± 34	± 9.7	200 feet

3.3 SUCCESS CRITERIA FOR TEST OBJECTIVE 3

For Test Objective 3 there should be a comparison made between the navigation accuracy achieved using LDGPS and that achieved using WDGPS. This should include individual comparisons of SE and TSE as a function of distance along the approach path.

SECTION 4

TEST CONFIGURATION

4.1 TEST BED

The major components of the NSTB are shown in figure 1. The following summarizes the functions of the major components.

4.1.1 Broadcast Satellite

The broadcast satellite for this test will be the Inmarsat AOR-West or AOR-East geostationary satellite. The main function of the broadcast satellite is to receive the WIB integrity alarms and differential corrections from the COMSAT ground earth station and broadcast them to the test aircraft. The satellite down-link used for this test will be a GPS like broadband signal at 1533.475 MHz and not the L1 carrier (1575.42 MHz) that will eventually be used for the WIB broadcast in the final system.

4.1.2 Earth Station Server

The Earth Station Server (ESS) will generate the GPS like signal and modulate the WIB and differential correction messages received from the Central Processing Facility (CPF) and transmit them to the Inmarsat satellite. The ESS is located in Southbury, CT. The ESS is connected to the CPF by a 19.2 Kbps data rate phone line.

4.1.3 Central Processing Facility

The main function of the Central Processing Facility (CPF) is to receive data from the monitor stations and compute the corresponding differential corrections and integrity status messages. Hardware at the CPF includes a 486 based communication/navigation workstation which is connected to a local area network (LAN). The CPF is located at the FAATC.

4.1.4 Remote Monitor Stations

The NSTB will use Remote Monitor Stations (RMSs) to provide separate pseudorange residuals and ionospheric measurements to the CPF. Hardware at the RMSs includes a GPS receiver and antenna, a 486 based computer, a weather station, and a modem for communication with the CPF through a dial-up telephone line. The weather stations at the monitor stations will be used to obtain meteorological data required for estimating tropospheric delay at the monitor station. RMSs will be located in Oldtown, ME, Dayton, OH, Georgetown, SC, and Reston, VA.

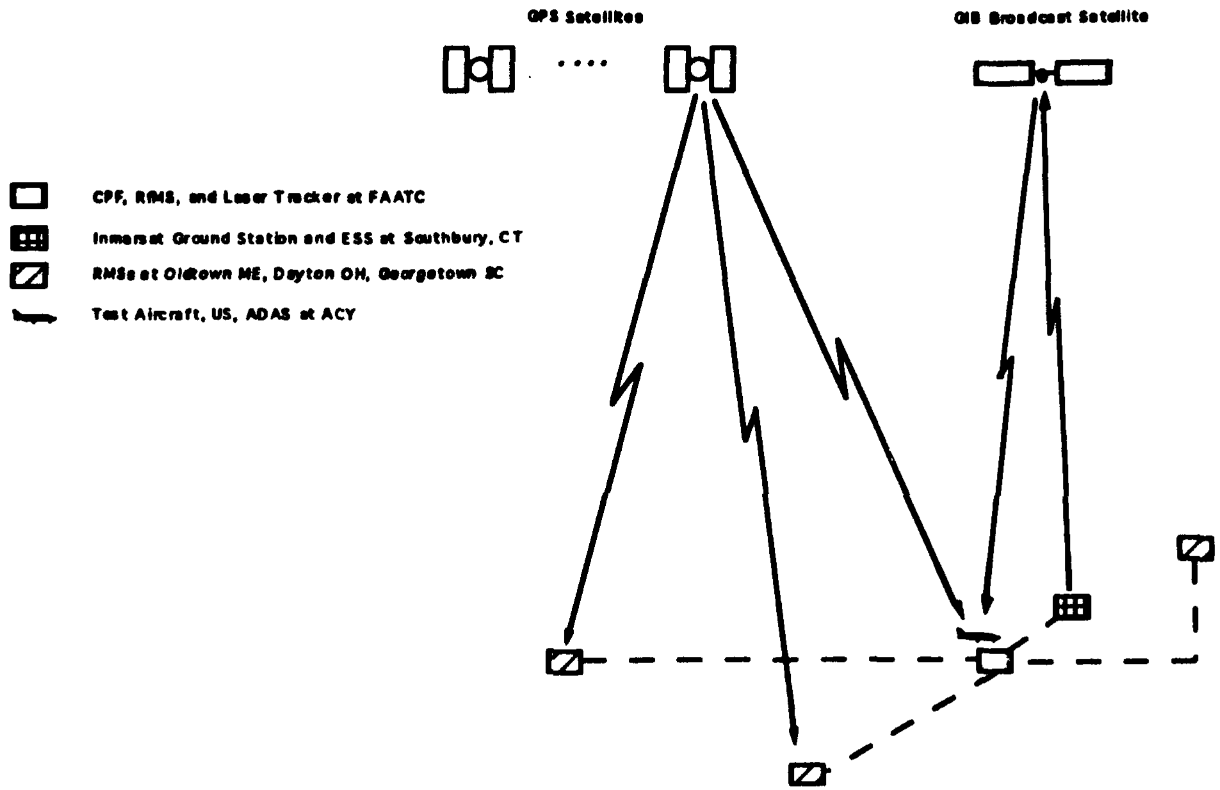


Figure 1. Scenario for Flight Tests

4.1.5 Reference Monitor Station

The Reference Monitor Station (RfMS) is collocated with the CPF at the FAATC. The RfMS would not normally be part of a final WDGPS system. Its purpose in this test is to provide LDGPS corrections which are being used for baseline comparison with WDGPS. Hardware at the RfMS is the same as that at the RMSs, except that the computer is connected to the CPF via an RS-232 connection.

4.1.6 Test Aircraft

The test aircraft will be a Convair 580.

4.1.7 User Station

The User Station (US) located on the aircraft combines the GPS satellite signals and the differential corrections to produce a navigation solution estimating the aircraft position. It consists of a VHF receiver for connecting to the LDGPS data link, a modified GPS receiver for receiving the GPS like WDGPS/WIB satellite broadcast, and two other GPS receivers for receiving the GPS satellite signals (see 4.2). It also includes a 486 based computer.

4.1.8 Aircraft Data Acquisition System

The Aircraft Data Acquisition System (ADAS) will accept navigation data from the US and provide corresponding outputs to the glide path and course deviation indicators in the cockpit. In addition, the ADAS will record and time stamp navigation data from the US and from other aircraft sensors (e.g., ILS, barometric altimeter, and INS). The ADAS is the primary data recording system on the test aircraft.

4.1.9 Laser Tracker

The Laser tracker at the FAATC will provide the truth position for sensor error and total system error data.

4.2 TEST ARTICLE

For the phase ID flight test, the US will contain an Ashtech M-XII GPS receiver and two NovAtel Model 1002 receivers.

One of the NovAtel receivers will be modified to receive the Inmarsat satellite broadcast. This will be accomplished by modifying the local oscillator in the receiver front end to translate the 1533.475 MHz carrier to the appropriate intermediary frequency (IF). Subsequent processing in the receiver will then be identical with normal GPS processing.

The other NovAtel receiver will be designated as the primary and the Ashtech receiver will be designated as the secondary navigation receiver for the duration of the test. The primary

receiver will be used to assess WDGPS accuracy and the secondary receiver will be used to assess the WIB.

The test aircraft also contains the software for processing the WIB broadcast and WDGPS and LDGPS messages on the test aircraft. The CPF will contain ionospheric delay estimation software, the integrity algorithm, and the software for calculating the wide-area differential corrections.

SECTION 5

OPERATIONAL SCENARIOS

This section of the plan contains a general description of the scenario, approach path to be flown, and the ground rules that will be observed when conducting phase ID tests and data analysis.

5.1 GENERAL

5.1.1 Test Objective 1

The time required to detect, transmit, process and receive an integrity alarm will be determined to satisfy Test Objective 1. An integrity alarm will be raised either when the pseudorange error from an RMS exceeds some specified maximum value or when the broadcast and measured corrections diverge and cause a WDGPS horizontal error that exceeds a specified maximum value. For testing purposes, the integrity alarms will be produced by lowering the threshold to 60 m. The US on the aircraft will record data on the integrity alarms.

The secondary GPS receiver (i.e., the Ashtech receiver) will be used to assess the use of the WDGPS/WIB broadcast for integrity determination. The US will estimate the horizontal position error using the broadcast differential corrections and the known satellite positions and compare this estimate to a specified horizontal threshold. If the estimated position error exceeds the threshold an integrity failure will be recorded. Post-test the integrity status will be compared to the uncorrected GPS horizontal position error to determine the integrity algorithm performance in terms of false alarms and missed detections.

The phases of flight applicable to the integrity algorithm and integrity response time tests are both the approach and the missed approach phase. Data for the entire period that the airplane is airborne will be collected and analyzed post-flight by STel and the FAATC (ACD-330) independently.

5.1.2 Test Objective 2

The second test objective is to collect and analyze WDGPS data . The diagram in figure 2 shows conceptually the relationship among the receivers in this test phase. Switch S1 in figure 2 will be set to select wide-area differential corrections from the modified NovAtel receiver (NovAtel 1 in figure 2). The unmodified NovAtel receiver (NovAtel 2) will be used to receive GPS satellite signals. The output of this receiver will be combined with the wide-area differential corrections to provide guidance to the pilot through onboard avionics.

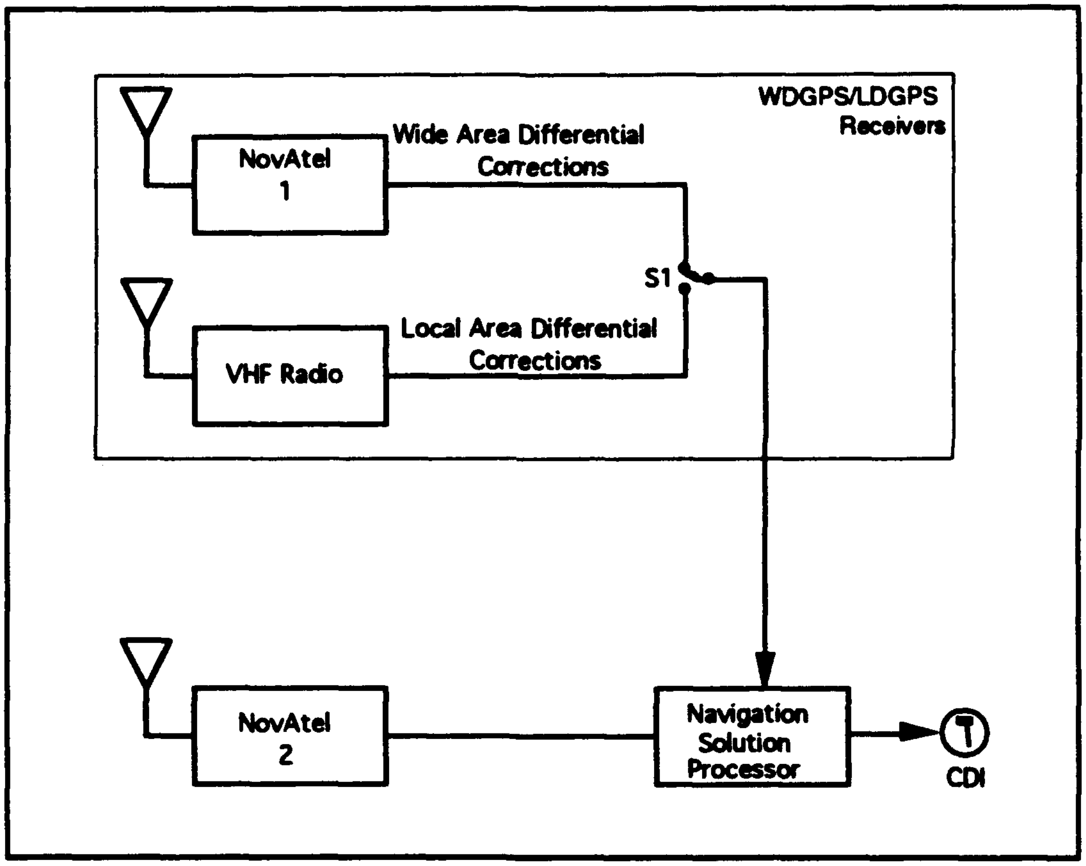


Figure 2. Receiver Conceptual Block Diagram

The WDGPS ionospheric correction will be computed using data from all the remote monitor stations located 500 miles or more from the reference monitor station (the Reston, VA RMS and the RfMS will be excluded). The WDGPS lumped clock and ephemeris correction will be computed as an average of the pseudorange corrections from all the remote monitor stations. The differential corrections will be formatted into a message and will be relayed to the US on board the aircraft by way of the Inmarsat satellite. The ionospheric delay estimation technique will be the technique described in [3].

Data for the entire period that the airplane is airborne is of interest during this portion of the test. All approaches will be straight in and will be flown in manual mode. Runway 13 at Atlantic City International Airport (ACY) will be the location for the test flights. The truth source will be the FAA Technical Center's laser tracker. Data for WDGPS corrections as well as flight path guidance will be analyzed by STel and the FAATC independently.

5.1.3 Test Objective 3

The third test objective is to collect and analyze LDGPS data . During this portion of the test switch S1 in figure 2 will be set to select local-area differential corrections from the VHF receiver. As in Test Objective 2, the unmodified NovAtel receiver (NovAtel 2) will be used to receive GPS satellite signals. The output of this receiver will be combined with the local-area differential corrections to provide guidance to the pilot.

The LDGPS corrections will be calculated using the pseudorange residuals obtained from the reference monitor station located at the airport. The differential corrections will be transmitted by way of the VHF radio link to the US onboard the aircraft.

Data for the entire period that the airplane is airborne is of interest during this portion of the test. All approaches will be straight in and will be flown in manual mode. Runway 13 at Atlantic City International Airport (ACY) will be the location for the test flights. The truth source will be the FAA Technical Center's laser tracker. Data for LDGPS corrections as well as flight path guidance will be analyzed by STel and the FAATC independently.

5.2 FLIGHT PATHS TO BE FLOWN

Figures 3 illustrates the path to be flown for this flight test. The flight segment prior to capturing the runway center line extension will be flown using a VHF Omni Range (VOR) radial or Air Traffic Control (ATC) vectors for guidance. The aircraft will make a turn onto the extended runway center line at an altitude of 2500 feet, beneath WP 1, using lateral guidance derived from WDGPS (Test Objective 2) or LDGPS (Test Objective 3). The aircraft will follow the extended runway centerline until it intercepts the waypoint defined glide path between WP 2 and WP 3. The aircraft using vertical guidance derived from WDGPS or LDGPS will descend on a glide path of 3 degrees. All approaches will end at the runway threshold, or sooner if the pilot determines that it would be unsafe to continue the

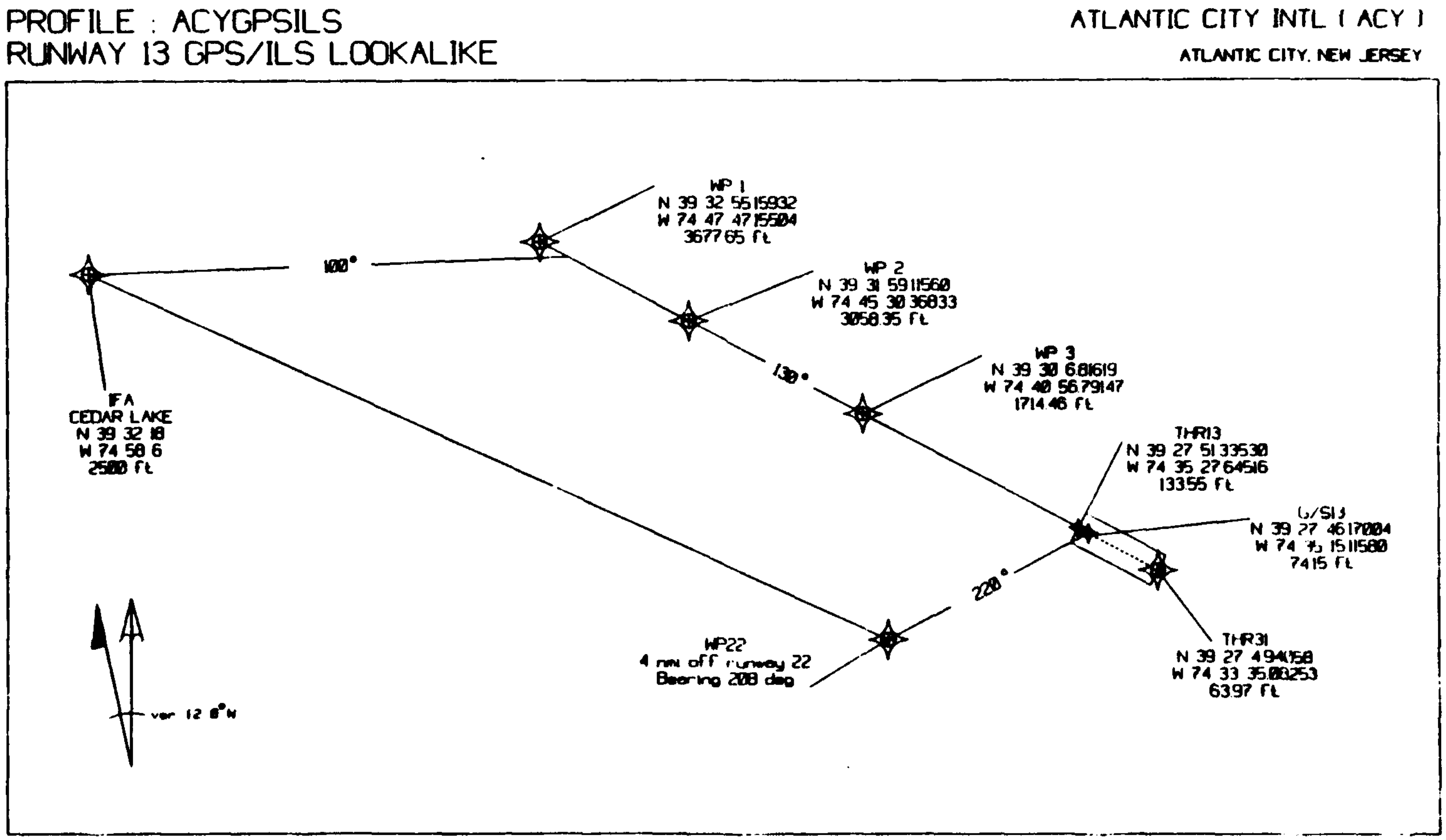


Figure 3. Illustration of Flight Path

approach. At this point, the aircraft will climb on a missed approach pattern and will position itself to repeat the procedure for the next approach.

5.3 GROUND RULES FOR CONDUCTING THE TEST

The following ground rules are for the purposes of ensuring a successful test campaign and uniform operational procedures among all the approaches so that statistical procedures can be more rigorously applied in the data analysis estimations and comparisons.

a. Data on the timeliness of integrity alarms will be collected continuously during data collection for Test Objective 1. Data for Test Objective 2 and Test Objective 3 will not be collected during this period.

b. The required sample size for integrity time-to-alarm test is 135 generated alarms to satisfy Objective 1. The rationale for the sample size is provide in section 9.

c. The collection of WDGPS data (for Test Objective 2) will be interleaved with collection of LDGPS data (for Test Objective 3). The first 20 WDGPS approaches will be interleaved with 20 LDGPS approaches. The rationale for the interleaving of WDGPS and LDGPS approaches is to ensure that similar GPS satellite geometry and environmental conditions exist for both.

d. At least 40 successful approaches for WDGPS will be completed to satisfy objective 2. More LDGPS approaches than the 20 specified above will be completed for Test Objective 3 if time permits, with continued interleaving with WDGPS approaches. The rationale for the number of approaches is provided in section 9.

e. The WDGPS ionospheric corrections will be computed using data from all the remote monitor stations located more than 500 miles from the reference monitor station. The lumped satellite clock and ephemeris corrections will be computed as an average of the pseudorange corrections from all the remote monitor stations as described in section 5.1.2. The LDGPS corrections will be computed using the reference monitor station at ACY as described in 5.1.3.

f. The broadcast WIB integrity alarms ("don't use" status) will be broadcast in place of a WDGPS differential correction. The broadcast lumped clock and ephemeris differential corrections for WDGPS will be provided to the test aircraft every 6 seconds. The broadcast ionospheric correction for WDGPS will be provided to the test aircraft every 5 minutes. The pseudorange corrections for LDGPS will be provided to the aircraft at least every 2 seconds.

g. The only sensor data to be used for guidance during the approach phase of the flight will be either WDGPS or LDGPS (both horizontal and vertical guidance will be provided).

h. The approaches will be conducted during periods when horizontal and vertical dilutions of precision are bounded by HDOP < 2, VDOP < 3.

i. The only outlier data that will be discarded from data reduction will be anomalies with known causes, such as laser tracker malfunction. The only decisions to exclude collected data from data reduction will be made jointly by ACD-330 and ARD-70.

j. All approaches will be conducted with manual steering.

k. The CDI/GSI driven by WDGPS or LDGPS will have the same scale sensitivities as the ILS localizer/glide slope.

l. The stabilized approach concept will be used for all approaches. No lower than 1000 ft above ground level (AGL), the aircraft will be on speed, on profile, and in an approved landing configuration.

m. The FAATC will have the reference antenna site and laser tracker precisely surveyed.

n. The FAATC will provide the approach plate for the test, and provide to STel the required precise WGS84/NAD83 coordinates to define the desired approach profile.

o. For testing purposes, the integrity alarms will be produced when any pseudorange correction from an RMS exceeds 60 m. An artificially low protection threshold has been chosen so that integrity alarms will be generated at a frequent rate. The alarms will be internally collected and time tagged, and will not be used to drive integrity flags in the cockpit avionics.

SECTION 6

REQUIRED END-RESULT STATISTICS

6.1 TEST OBJECTIVE 1

For the data collected for Test Objective 1, the sample mean, maximum value observed, standard deviation, probability histogram, cumulative distribution statistics, and the upper limit of the 95 percent confidence interval of the mean and standard deviation will be calculated for the following data types. Refer to appendix A, Test Concepts, for the definition of these time intervals.

a. Integrity interrupt time-to-alarm (total time-to-alarm)
b. Correction latency for each error component
c. RMS receiver data latency
d. Monitor station processing
e. RMS data transmission delay
f. CPF processing delay
g. CPF-to-ESS data transmission delay
h. ESS processing/wait
i. Inmarsat delay

The following results will be obtained for Test Objective 1:

a. Plots of the probability histograms, cumulative distributions, means, and standard deviations

b. Tabular summaries of the above statistics

6.2 TEST OBJECTIVE 2

For the WDGPS data collected for Objective 2, the ensemble mean, standard deviation and maximum error statistics will be calculated. Statistics for the following error types will be calculated, including the upper limit of the 95 percent confidence interval. Refer to appendix A, Test Concepts, for definitions and conventions to be followed.

a. Vertical SE: Vertical position - laser tracker truth
b. Vertical TSE: Laser tracker truth - desired vertical position
c. Vertical FTE: - GSI command
d. Cross-track SE: XTRK position - laser tracker truth
e. Cross-track TSE: Laser tracker truth - desired lateral position
f. Cross-track FTE: - CDI command

g. Along-track SE: ATRK position - laser tracker truth (Note: along track TSE and FTE are not included since there is no along track guidance).

The following results will be obtained for Test Objective 2:

a. Plots of the ensemble statistics as a function of distance along the horizontal approach path

b. Calculated TSE statistics based on the sum of SEs and FTEs, and comparison with measured TSE

c. Individual approach graphs of cross-track and vertical trajectories of SEs and TSEs and any other results as specified by AFS/AIR/AVN

d. Tabular summaries

e. An analysis of all wide-area error components including: ionospheric errors, tropospheric errors, satellite ephemeris errors, and message format errors

f. An analysis of the impact of update rates for the different error components.

6.2 TEST OBJECTIVE 3

For the LDGPS data collected for Objective 3, the ensemble mean, standard deviation and maximum error statistics will be calculated. Statistics for the following error types will be calculated, including the upper limit of the 95 percent confidence interval. Refer to appendix A, Test Concepts, for definitions and conventions to be followed.

a. Vertical SE: Vertical position - laser tracker truth
b. Vertical TSE: Laser tracker truth - desired vertical position
c. Vertical FTE: - GSI command
d. Cross-track SE: XTRK position - laser tracker truth
e. Cross-track TSE: Laser tracker truth - desired lateral position
f. Cross-track FTE: - CDI command
g. Along-track SE: ATRK position - laser tracker truth (Note: along track TSE and FTE are not included since there is no along track guidance).

The following results will be obtained for Test Objective 3:

a. Plots of the ensemble statistics as a function of distance along the horizontal approach path

b. Calculated TSE statistics based on the sum of SEs and FTEs, and comparison with measured TSE

c. Individual approach graphs of cross-track and vertical trajectories of SEs and TSEs and any other results as specified by AFS/AIR/AVN

d. Tabular summaries

e. An analysis of all message format errors

f. An analysis of the impact of update rates

g. A comparison of the performance obtained using LDGPS with that obtained using WDGPS (from Test Objective 2). This should include individual comparisons of SE and TSE as a function of distance along the approach path.

SECTION 7

DATA COLLECTION AND REDUCTION

7.1 GENERAL METHOD FOR DATA COLLECTION AND REDUCTION

Data will be collected on the aircraft and from the ground truth source for the calculation of the integrity time-to-alarm, SE, FTE, and TSE and other statistics described in section 6. Sections 7.2 and 7.3 provide the minimum data to be collected on the ground and on the aircraft. Section 5.3 contains the recommended number of approaches for each objective. An observer log will be kept (e.g., start and stop time of each run, weather conditions at time of test, and anomalies).

7.1.1 Coordinates

The aircraft-derived sensor data will be with lat/long/altitude coordinates, relative to the geodetic model used (WGS84). This data will be transformed into a suitable local tangent plane coordinate system with cross-track, along-track, and altitude values to provide guidance for the approaches. The spherical coordinate output from the laser tracker will be transformed into the same local tangent plane.

7.1.2 Lever-Arm Correction

A lever-arm correction will be applied to the data to account for the difference in position between the laser reflector and the GPS antenna. The laser reflector position data will be translated to the GPS antenna. The transformation of the laser reflector position will be accomplished with a three-dimensional coordinate rotation and coordinate translation which will not only account for the horizontal and vertical differences between the laser reflector and the GPS antenna, but also the pitch, roll, and yaw of the aircraft.

7.1.3 Errors

The cross-track, along-track, horizontal radial and vertical SEs are obtained by subtracting the laser tracker truth values from the aircraft derived values as indicated in section 6. The cross-track TSE will be calculated as the perpendicular distance in the horizontal plane between the aircraft's position (based on laser tracker truth) and the desired horizontal approach path. The vertical TSE will be calculated as the difference in altitude between the aircraft position (based on the laser tracker truth) and the desired vertical approach profile. The cross-track FTE will be derived from the negative of the course deviation indicator (CDI) command. The vertical FTE will be derived from the negative of the glide slope indicator (GSI) command.

7.1.4 Simultaneity of Collected Data

Recognizing the importance of simultaneity in obtaining accurate results for vertical errors, its integrity will be established. Since the laser tracker outputs are time tagged relative to

UTC, and GPS time is synchronized with UTC time within ±300 ns (95 percent) plus an integral number of leap seconds, the data from GPS should be able to be synchronized to the data from the laser tracker by correcting for the number of leap seconds. The maximum time synchronization error between all aircraft and ground data and truth should be < 5 ms.

7.2 GROUND DATA TO BE COLLECTED

Table 3 contains the minimum data to be collected on the ground to satisfy the desired end-result statistics.

7.3 AIRCRAFT DATA TO BE COLLECTED

Table 4 contains a list of the minimum data to be collected at the aircraft for the desired major end-result statistics to satisfy the objectives of Phase I. All data in table 4 will be recorded by the airborne data acquisition system (ADAS). WDGPS and LDGPS position coordinates will be based on the WGS84 coordinate system.

7.4 HANDLING OF DISCARDED DATA

The test log shall clearly identify any outlier data that is discarded (see paragraph 5.3.i). Both the test log and the test report shall clearly identify the event and reason for discarding any data collected during the flight tests.

Table 3. Phase ID Minimum List of Data to be Collected on Ground.

Data	Resolution	Units	Update
• Laser Tracker			
Latitude of test airplane	0.000001	ft	10 Hz
Longitude of test airplane	0.000001	ft	10 Hz
Height of test airplane	0.000001	ft	10 Hz
Time GPS UTC	0.000001	s	10 Hz
• Central Processing Facility			
Time GPS measurement data received at CPF	0.001	s	
Time CPF integrity processing begun	0.001	s	
Time CPF data transmitted to ESS	0.001	s	
Pseudorange corrections for LDGPS	0.001	m	1 Hz
Pseudorange rate corrections for LDGPS	0.001	m/s	1 Hz
Iono correction for WDGPS	0.001	m	1 Hz
Lumped clock/ephemeris correction for WDGPS	0.001	m	1 Hz
Broadcast pseudorange correction for LDGPS	0.2	m	(NOTE 1)
Broadcast pseudorange rate correction LDGPS	0.02	m/s	(NOTE 1)
Broadcast iono correction for WDGPS	0.2	m	(NOTE 1)
Broadcast clock/ephemeris correction for WDGPS	0.2	m	(NOTE 1)
Time SV declared failed, ID of SV	0.001	s	1 Hz
Time SV declared OK, ID of SV	0.001	s	1 Hz
• Remote Monitor Stations			
GPS measurement time of validity (provided by Rogue receiver)	0.001	s	1 Hz
Pseudorange measurements for each SV in view	0.001	m	1 Hz
Ionospheric delay	0.001	m	1 Hz
Tropospheric delay	0.001	m	1 Hz
• Reference Monitor Stations			
Time GPS measurement data available at monitor station PC	0.001	s	
Time GPS measurement data transmitted to CPF	0.001	s	
Pseudorange measurements for each SV in view	0.001	m	1 Hz
• Earth Station Server			
Time CPF data received by ESS	0.001	s	
Time ESS data sent to Inmarsat satellite	0.001	s	

NOTE 1: Broadcast pseudorange correction and correction rate update rate depends on the WDGPS/WIB message rate and the number of satellites being tracked.

Table 4. Phase ID Minimum List of Data to be Collected on Aircraft.

Data	Resolution	Units	Update
• GPS Receiver			
GPS Time	0.001	s	2 Hz
ECEF Position - X	0.01	m	2 Hz
ECEF Position - Y	0.01	m	2 Hz
ECEF Position - Z	0.01	m	2 Hz
ECEF Velocity - X	0.001	m/s	2 Hz
ECEF Velocity - Y	0.001	m/s	2 Hz
ECEF Velocity - Z	0.001	m/s	2 Hz
Uncorrected pseudoranges (for each SV in solution)	0.1	m	2 Hz
SVs used in solution			2 Hz
HDOP, VDOP	0.1		2 Hz
• Navigation Solution Processor			
Pseudorange correction (for each SV in solution)	0.001	m	2 Hz
Pseudorange rate correction for each SV for LDGPS	0.001	m/s	2 Hz
Time correction data received at US	0.001	s	
Age of correction data when received	0.001	s	
Time correction data applied to solution	0.001	s	
Time WIB "don't use" message received	0.001	s	
GPS lateral deviation (NOTE 2)			
GPS vertical deviation (NOTE 2)			
• INS			
Roll (NOTE 2)			
Pitch (NOTE 2)			
Yaw (NOTE 2)			
• ILS			
ILS localizer (lateral deviation) (NOTE 2)			
ILS glide slope (vertical deviation) (NOTE 2)			
• Aircraft Sensors			
Barometric altitude (NOTE 2)			

NOTE 2: The resolution, units, and update rates for these items are unknown and must be confirmed with CTA.

SECTION 8

DATA ANALYSIS

In general, the statistical estimations identified in section 5 will be calculated from the data. The estimations will be bounded by the upper limit of the 95 percent confidence interval of the mean and standard deviation, using the t-distribution and chi-square distributions, respectively.

8.1 INTEGRITY PERFORMANCE

The protection limit of the integrity algorithm will be set so that integrity alarms will be generated at a frequent rate. Estimates of the upper limit of the 95 percent confidence interval of the mean and standard deviation of the time intervals discussed in section 6 will be calculated. Probability histograms and cumulative distributions of these time intervals will be plotted.

8.2 TOTAL SYSTEM ERROR

The absolute value of the measured cross-track and vertical mean plus two-sigma TSEs will be plotted versus distance along the flight path. In addition, the calculated cross-track and vertical TSEs will be derived from the sum of the respective SE and FTE means and two-times the root-sum-square of the SE and FTE standard deviations. These two estimates of TSE will be statistically compared. In addition, the cross-track and vertical TSEs will be compared with the Tunnel-In-Space required navigation performance (RNP) for applicable points along the flight path. The inner nominal performance surface TSE (95 percent) requirements are provided in table 5, and the outer aircraft containment surface (10^{-7}) requirements are provided in table 6 [2]. Both tables assume a 3 degree glide slope and a 55 foot threshold crossing height. Heights are above threshold.

Table 5. Inner Nominal Performance Surface TSE (95 percent). (Half widths in Feet)

Height	GPI	50	100	200	250	300	400	500	750	1000	1250	1500
Lateral	27	51	75	110	118	125	158	192	275	358	442	525
Vertical	0	NA	15	32	36	40	51	62	89	116	143	170

Table 6. Outer Aircraft Containment Surface (10^{-7}). (Half widths in Feet)

Height	GPI	50	100	200	250	300	400	500	750	1000	1250	1500
Lateral	200	245	325	425	448	470	564	658	894	1129	1365	1600
Vertical	0	NA	65	110	123	135	165	196	272	348	424	500

8.3 SENSOR ERROR

The upper 95 percent confidence limits for the cross-track and vertical SE standard deviations will be compared to the Category I sensor accuracy requirements as stated in the 1992 Federal Radionavigation Plan and to the recorded ILS performance at the decision height and at other points used in flight inspection.

Individual approaches will be analyzed in detail if their results indicate unanticipated results relative to the mean +/- two-sigma. In these cases the effect of such conditions as navigation sensor status and laser tracker status will be analyzed, and decisions to include or exclude data will be based on a consensus between ACD-330 and ARD-70.

SECTION 9

FLIGHT SCHEDULE ANALYSIS

This section provides estimates for the sample size and the number of approaches required for Test Objectives 1 and 2 in order to obtain statistically significant results for the data analysis.

9.1 REQUIRED SAMPLE SIZE FOR TEST OBJECTIVE 1

Using the criterion of obtaining reasonably small errors for the estimate of the time-to-alarm, the sample size estimate is based on the following approach.

The integrity time-to-alarm specification is a not-to-exceed requirement. To ensure, with a high level of confidence, that the time-to-alarm requirement is satisfied would require an impractically large sample size. Therefore, for this test, we selected a sample size n=135 so that it can be asserted with 99.5 percent confidence that at least 95 percent of the distribution will be less than the largest observation in the sample. This will hold for any distribution of measurements [4].

9.2 REQUIRED NUMBER OF APPROACHES

Using the criterion for obtaining a reasonably small upper confidence limit for the standard deviation of WDGPS and LDGPS vertical errors, it was estimated that the minimum sample size for WDGPS will be 40 approaches and for LDGPS will be 20 approaches. As the sample size decreases from 20, the upper confidence limit begins to rapidly increase as indicated in figure 4. However, increasing the sample size beyond 20 does not appreciably reduce the upper confidence limit.

9.3 RECOMMENDED SEQUENCE OF APPROACHES

The recommended sequence of approaches is to complete 40 WDGPS interleaved with 20 LDGPS approaches. The first 20 WDGPS approaches will be interleaved with the 20 LDGPS approaches. At this point, if time permits additional LDGPS approaches will be interleaved with WDGPS approaches until a total of 40 WDGPS approaches have been completed. If time does not permit the additional LDGPS approaches to be performed, then only WDGPS approaches will be performed until a total of 40 have been completed.

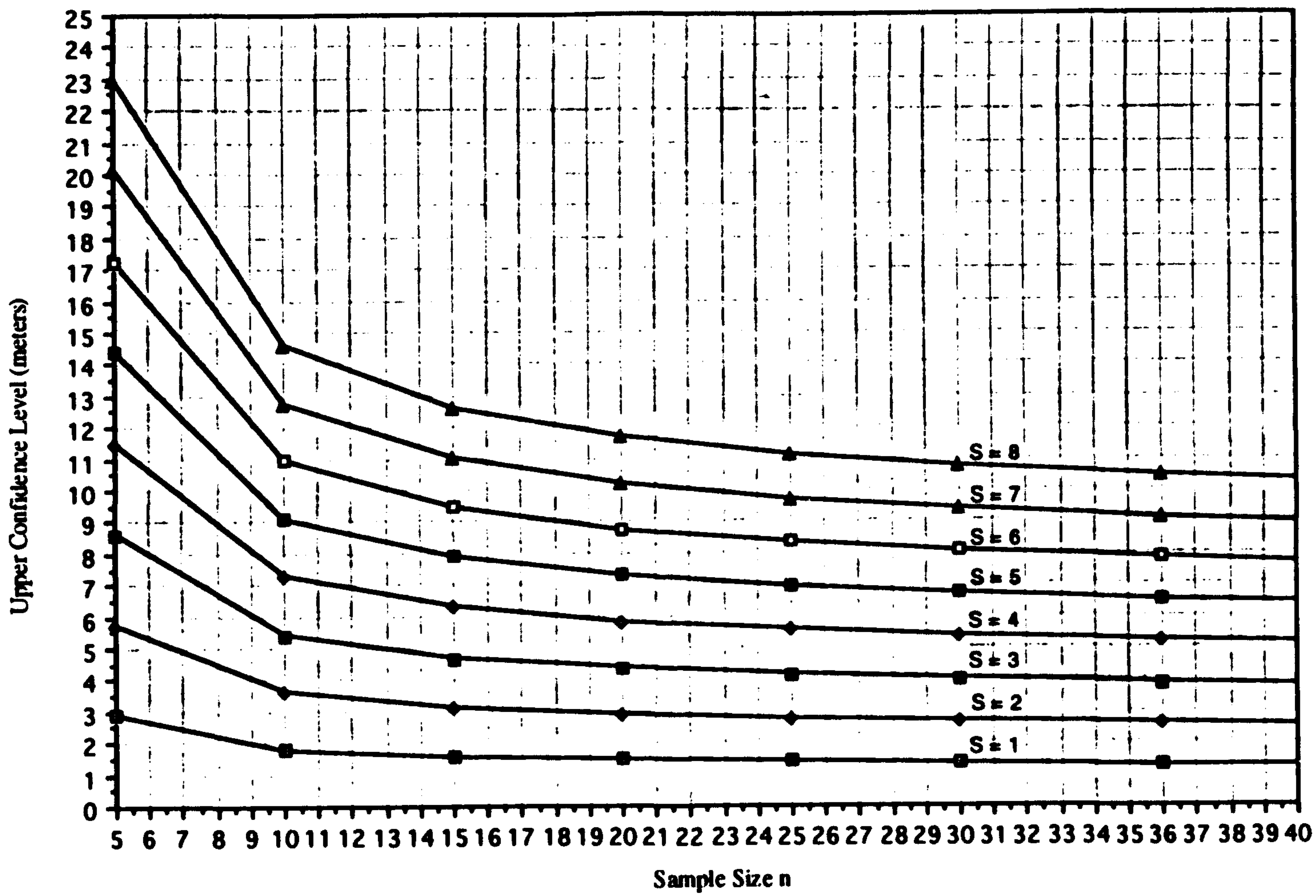


Figure 4. Upper Confidence Level (95%) of Standard Deviation of a Normal Variate

SECTION 10

PHASE ID INSTRUMENTATION

This section contains information on the instrumentation that will be used for the Phase ID flight test.

10.1 POSITIONING TRUTH

The main truth source for aircraft position is the laser tracker. The laser tracker is provided and operated by the FAA Technical Center.

10.1.1 Laser Tracker

The General Telephone and Electronic (GTE) Precision Automated Tracking System (PATS) uses an infrared laser beam to illuminate and automatically track cooperative targets.

a. Azimuth and elevation angle accuracy: 20 arcsec

b. Range Accuracy:
   1 ft, range < 5 nmi
   2 ft, 5 < range < 10 nmi
   5 ft, range = 25 nmi

c. Range of coverage: 7 - 10 nmi during normal operations at the FAATC

d. The PATS data will be time tagged using UTC with resolution of 1 μs

10.2 NAVIGATION SYSTEM

The WDGPS avionics, CPF, RfMS and RMSs will be provided by the FAA/STel. The FAA will provide the test aircraft and ADAS. Figure 5 is a top-level block diagram of the test bed configuration that will be available for the tests.

STel and ACD-330 will coordinate to ensure that the collection of all sensor data and flight technical error data is synchronized to within 5 ms to the laser tracker data collection.

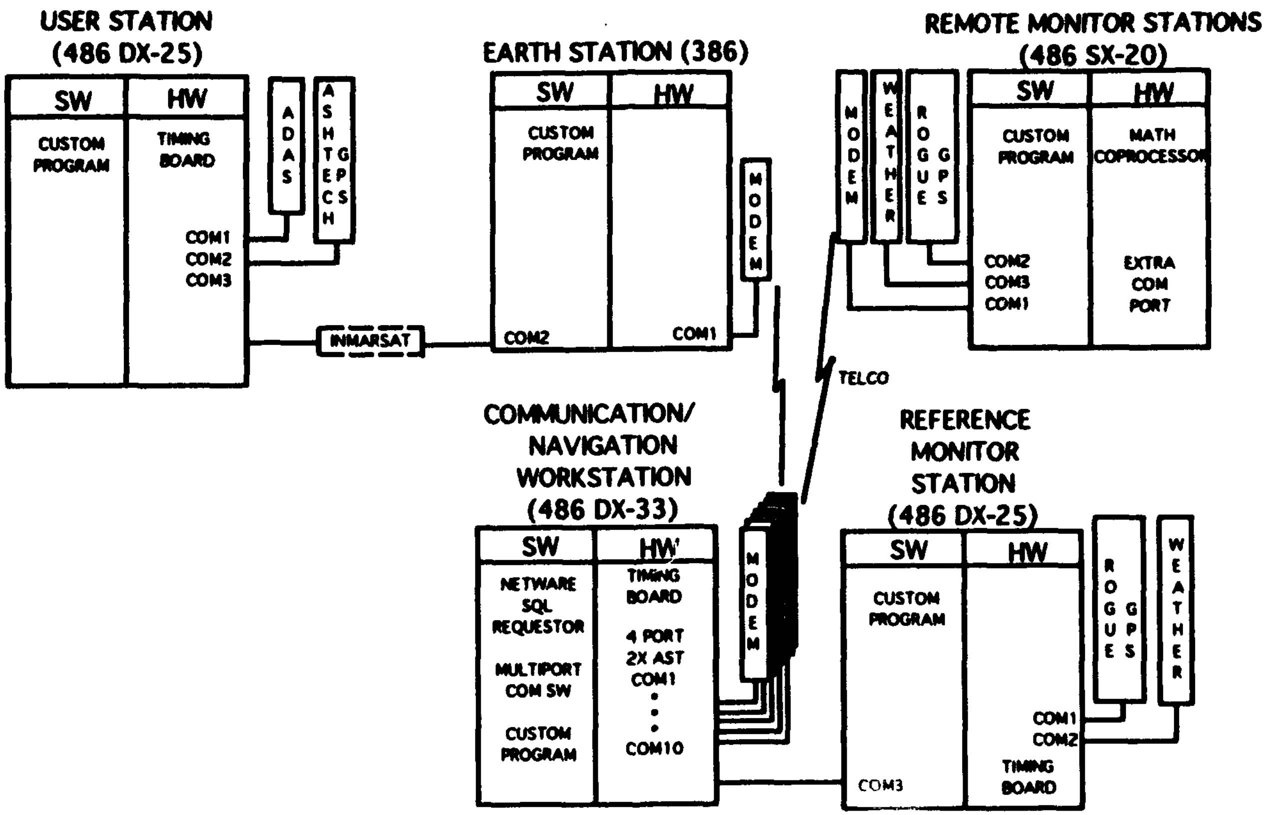


Figure 5. Test Bed Configuration

SECTION 11

QUALITY CONTROL AND PREPARATIONS

In order to prevent the flight test results from being contaminated by any errors that would not be encountered in the implemented WDGPS system the following quality control procedures will be performed:

a. ACY ATC will be briefed on planned flights.

b. The test aircraft will be stationed above a calibration survey point on the ramp apron where laser tracker and LDGPS data will be collected for 5 minutes prior to each day's flight.

c. Time synchronization between truth and ground and airborne recorded data will be maintained within 5 ms (synchronization accuracy will be worked out between STel and the FAA).

d. Tracker personnel will be informed of planned flights, and have the laser tracker calibrated.

e. The laser tracker will be calibrated at the beginning of each day prior to flights, and at the end of each day. Differences between the two calibrations will be noted.

SECTION 12

PHASE ID PROJECT RESPONSIBILITIES

The following are the organizational responsibilities for Phase ID:

FAA, ARD-70:

a. Provide overall program management and funding

FAA, ACD-330:

a. Provide test aircraft and coordinate its schedule and installation of equipment

b. Responsible for the ADAS including the pilot display

c. Install WDGPS ground-based equipment with antenna at surveyed point

d. Provide NAD83 survey of all reference points, such as LDGPS reference antenna, midpoint of runway threshold, ramp check, and any other required coordinate data

e. Provide way points for the approach of figure 3

f. Ensure proper location of laser retroreflector on aircraft

g. Provide laser tracking

h. Serve as flight test director

i. Merge tracking data with flight data

j. Reduce and plot data

k. Analyze data

l. Draft reports

FAA, ACN-302:

a. Provide laser tracker personnel and data

b. Assist in ensuring time synchronization between truth and airborne data acquisition system

STel:

a. Provide the necessary avionics and LDGPS and WDGPS ground-station equipment for all test objectives

b. Support ACD-330 in the data reduction and analysis

c. Support ACD-330 in the preparation of reports

d. Make sure that all collected data are synchronized with the truth within 5 ms

MITRE:

a. Prepare test plan

SECTION 13

REQUIRED APPROVALS PRIOR TO PUBLICATIONS

The following organizations and individuals or their designated representatives must approve, in writing, any and all draft results or the release of data before the publication or release of any results or data:

a. AFS-400 (Jim Crowling and/or Jim Enias)
b. ARD-70 (Joe Dorfler)
c. ACD-330 (Bob Till and/or Frank Persello)
d. STel (Bryant Elrod)

The following organizations and individuals must approve, in writing, the final report:

a. AFS-400 (Jim Crowling and/or Jim Enias)
b. ARD-70 (Joe Dorfler)
c. ACD-330 (Bob Till and/or Frank Persello)

SECTION 14

SCHEDULE

The following is the schedule for the flight tests, data reduction and analysis, and preparation of briefing and reports.

a. Flight tests take place during August 1993. Prior to terminating the flight tests the test director shall query all participants to determine whether the number of flights conducted was sufficient.

b. Data reduction and analysis will be performed between August and September 1993.

c. Preliminary results of the flight tests will be presented by 15 September 1993.

d. Final results in the form of a test report will be completed by 1 January 1993.

LIST OF REFERENCES

1. 1992 Federal Radionavigation Plan.

2. FAA SOIT STC, November 1992, "The Tunnel Concept: The Path to the Future".

3. El-Arini, M. B. and P. O'Donnell, P. Kellam, J. Klobuchar, T. Wisser, P. Doherty, January 21, 1993, "The FAA Wide Area Differential GPS (WADGPS) Static Ionospheric Experiment," Paper presented at the 1993 National Technical Meeting of the Institute of Navigation.

4. Walpole, R. E. and R. H. Myers, 1978, *Probability and Statistics for Engineers and Scientists*, New York: Macmillan, p. 491.

APPENDIX A

TEST CONCEPTS

This appendix contains definitions and conventions to be used in data collection and analysis.

A.1 ACCURACY TEST CONCEPTS

Sensor data collected from the WDGPS and LDGPS systems will be compared with the FAATC's laser tracker which will represent truth. Vertical error, cross-track error, and along track errors will be calculated. Figures A-1 and A-2 provides an illustration of these components of sensor error, and sign conventions to be used in the data reduction and analysis. Definitions of sensor error, flight technical error, and total system error are provided below.

a. *Sensor Error* (SE) is the sensor deviation from ground truth.

b. *Flight Technical Error* (FTE) is the aircraft deviation from the desired path as indicated to the pilot.

c. *Total System Error* (TSE) is the aircraft deviation from the desired flight path.

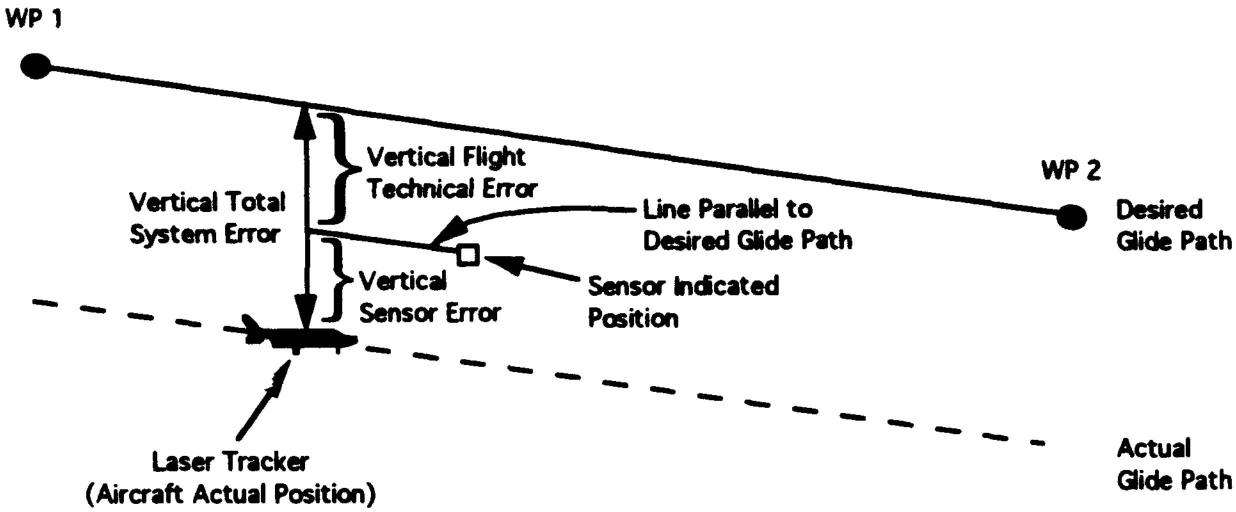
A.2 INTEGRITY TEST CONCEPTS

Definitions of the various time measurements used in the integrity time-to-alarm test are provided below. Figure A-3 provides an illustration of these measurements.

a. *Integrity interrupt time-to-alarm* is defined as the time the integrity message is received at the US minus the GPS measurement time of validity of the first measurement that resulted in the integrity alarm measured at the RMS.

b. *Correction latency* is defined as the time the differential correction message is received at the US minus the GPS measurement time of validity measured at the RMSs.

c. *RMS receiver data latency* is defined as the time the GPS measurement data is available at the reference monitor station receiver minus the GPS measurement time of validity at the remote monitor station.



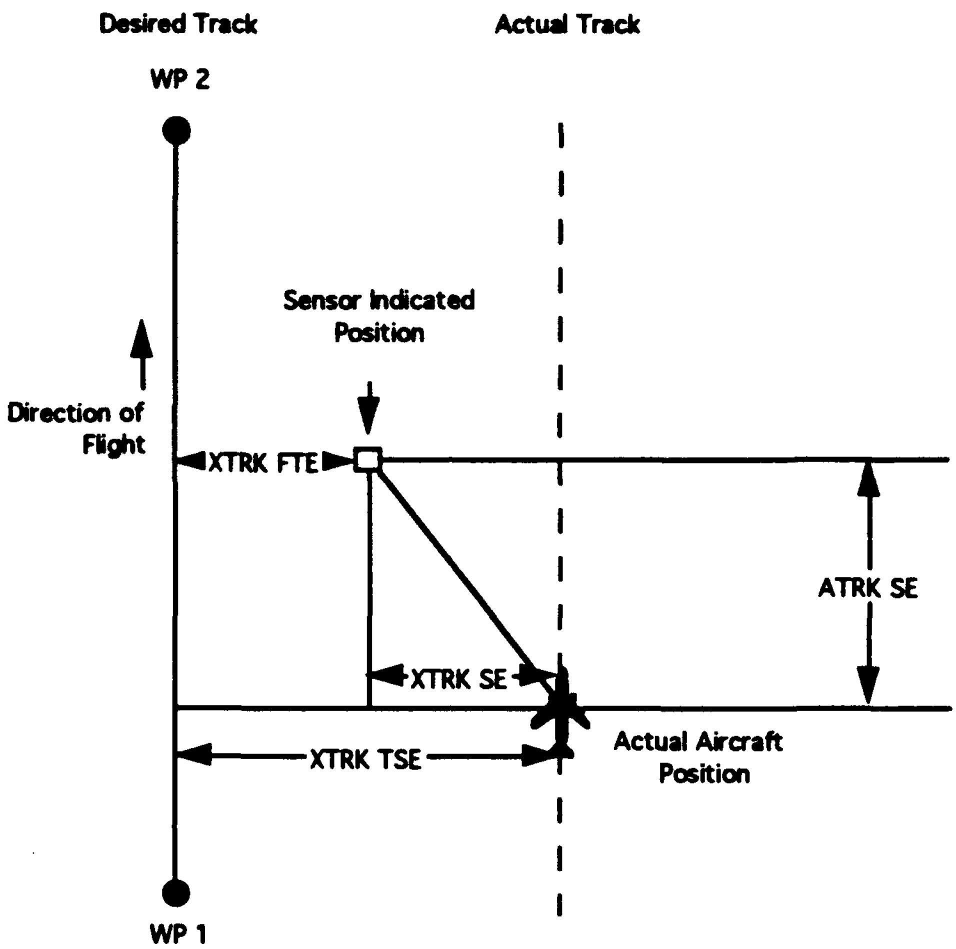
Vertical TSE = Desired Altitude - Tracker Altitude

Vertical SE = Projection of Sensor Altitude Along the Line Parallel to the Desired Glide Path - Tracker Altitude

Vertical FTE = Desired Altitude - Projection of Sensor Altitude Along the Line Parallel to the Desired Glide Path

Sign Convention / Error Type	Positive Sign	Negative Sign
Vertical Sensor Error	Sensor indicated position above aircraft actual position	Sensor indicated position below aircraft actual position

Figure A-1. Convention for Vertical Errors



Error Type \ Sign Convention	Positive Sign	Negative Sign
Sensor Cross-Track Error	Sensor indicated position to the left of the actual aircraft position	Sensor indicated position to the right of the actual aircraft position
Sensor Along-Track Error	Sensor indicated position in front of actual aircraft position	Sensor indicated position behind actual aircraft position

Figure A-2. Convention for Lateral Errors

1 Integrity interrupt time-to-alarm
2 Correction latency
3 Rogue receiver data latency
4 Monitor station processing
5 RMS data transmission delay
6 CPF processing delay
7 CPF-to-ESS data transmission delay
8 ESS processing/wait
9 Inmarsat delay

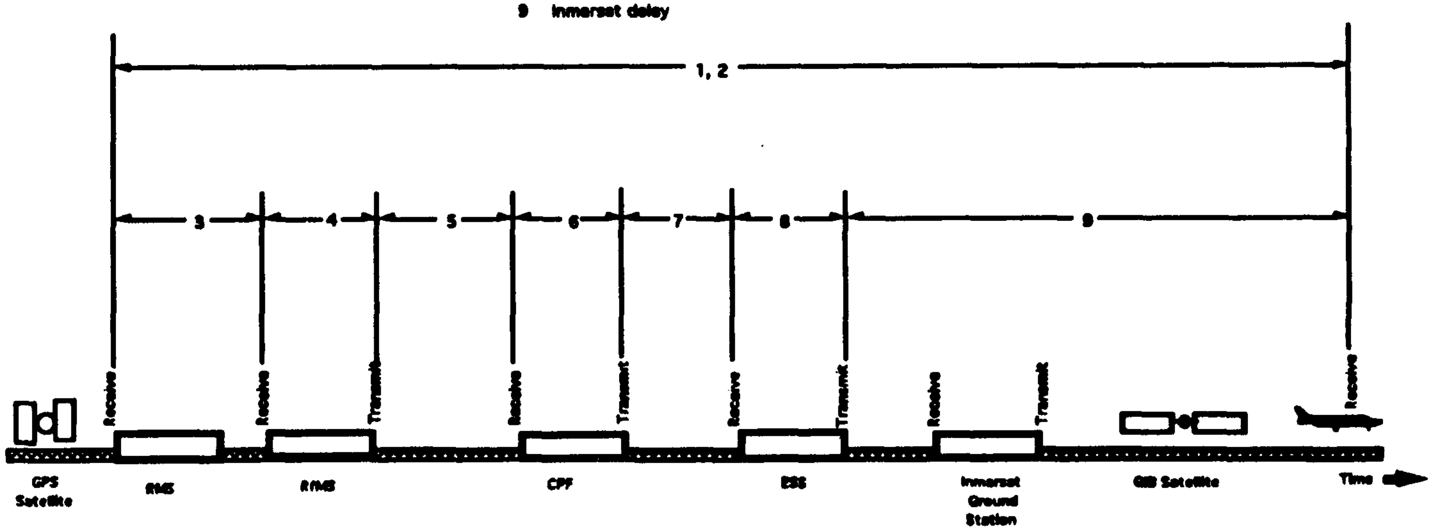


Figure A-3. Timeline Diagram

d. *Monitor station processing* is defined as the time the GPS measurement data is transmitted from the RfMS to the CPF minus the time the GPS measurement data was received at the RfMS.

e. *RMS data transmission delay* is defined as the time the GPS measurement data is received at the CPF minus the time the GPS measurement data was transmitted to the CPF at the RfMS.

f. *CPF processing delay* is defined as the time the CPF data is transmitted to the ESS minus the time the GPS measurement data is received at the CPF.

g. *CPF-to-ESS data transmission delay* is the time the CPF data is received at the ESS minus the time the CPF data is transmitted to the ESS.

h. *ESS processing/wait delay* is the time the ESS data is provided to the Inmarsat ground station minus the time the CPF data was received by the ESS.

i. *Inmarsat delay* is the time the data is received at the US minus the time the ESS data was sent to Inmarsat ground station.

GLOSSARY

ACRONYMS

ACY	Atlantic City International Airport
AGL	Above Ground Level
AOR	Atlantic Ocean Region
ADAS	Aircraft Data Acquisition System
ATC	Air Traffic Control
ATRK	Along Track
CAT I	Category I
CDI	Course Deviation Indicator
CPF	Central Processing Facility
ESS	Earth Station Server
FAA	Federal Aviation Administration
FAATC	FAA Technical Center
FTE	Flight Technical Error
GPS	Global Positioning System
GSI	Glide Slope Indicator
GTE	General Telephone and Electronic
HDOP	Horizontal Dilution of Precision
IF	Intermediary Frequency
ILS	Instrument Landing System
INS	Inertial Navigation System
LDGPS	Local-area Differential GPS
LAN	Local Area Network
NSTB	National Satellite Test Bed
PATS	Precision Automated Tracking System
RfMS	Reference Monitor Station
RMS	Remote Monitor Station
RNP	Required Navigation Performance
SE	Sensor Error

STel	Stanford Telecommunications
TSE	Total System Error
US	User Station
UTC	Universal Time Coordinated
VDOP	Vertical Dilution of Precision
VHF	Very High Frequency
VOR	VHF Omni Range
WDGPS	Wide-area Differential GPS
WIB	Wide-area Integrity Broadcast
WP	Way Point
XTRK	Cross Track